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FIG. 1

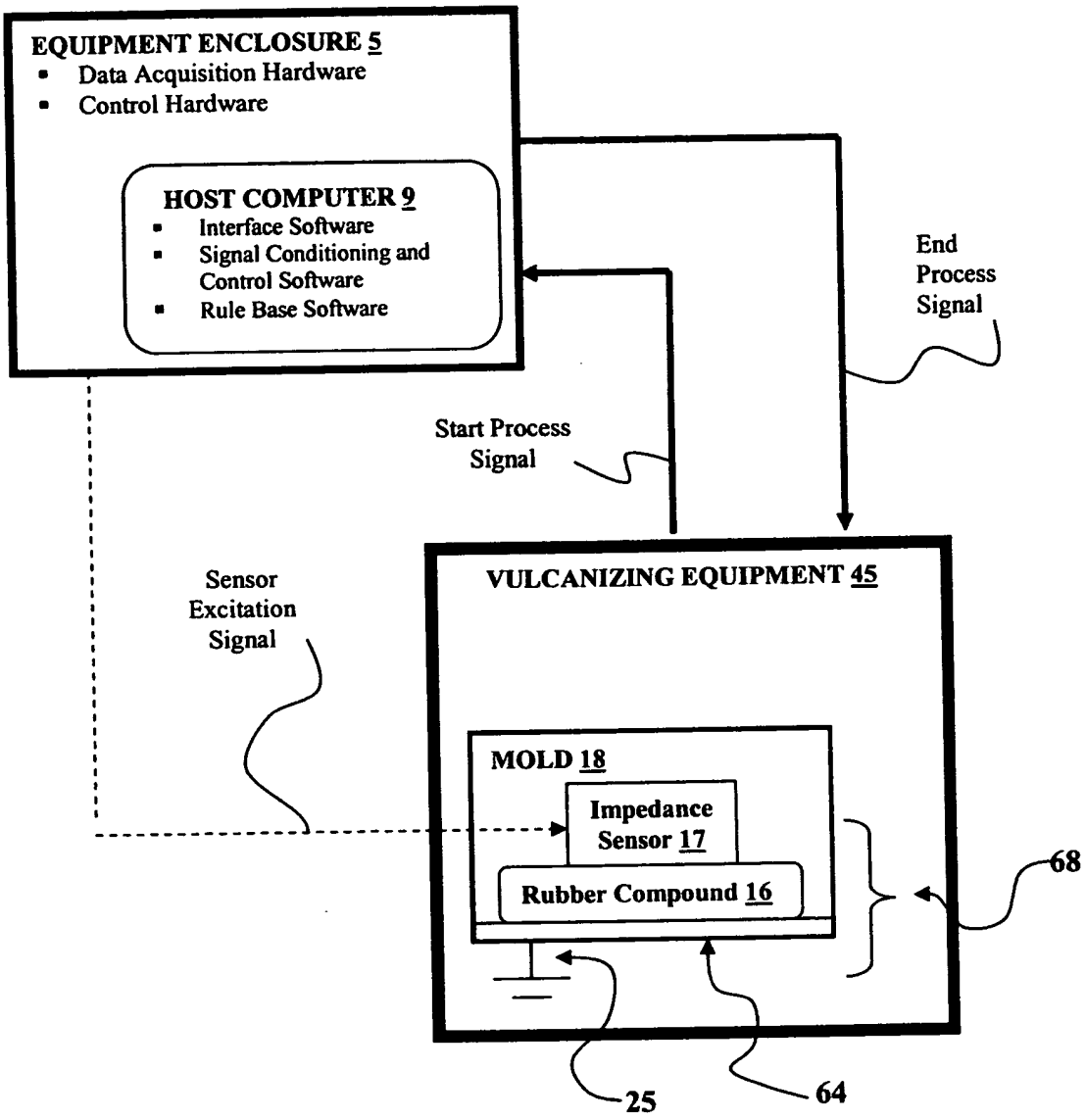

EQUIPMENT ENCLOSURE 5
Data Acquisition Hardware
Control Hardware
HOST COMPUTER 9
Interface Software
Signal Conditioning and Control Software
Rule Base Software
End Process Signal
Start Process Signal
Sensor Excitation Signal
VULCANIZING EQUIPMENT 45
MOLD 18
Impedance Sensor 17
Rubber Compound 16
68
25
64

FIG. 2

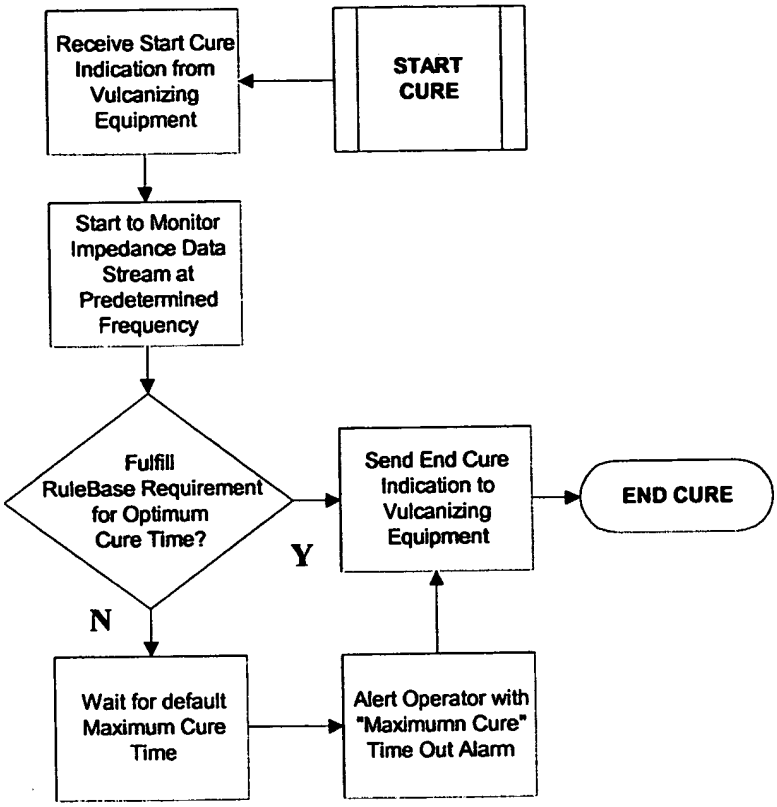

START CURE
Receive Start Cure Indication from Vulcanizing Equipment
Start to Monitor Impedance Data Stream at Predetermined Frequency
Fulfill RuleBase Requirement for Optimum Cure Time?
Y
N
Send End Cure Indication to Vulcanizing Equipment
END CURE
Wait for default Maximum Cure Time
Alert Operator with "Maximumn Cure" Time Out Alarm

FIG. 3

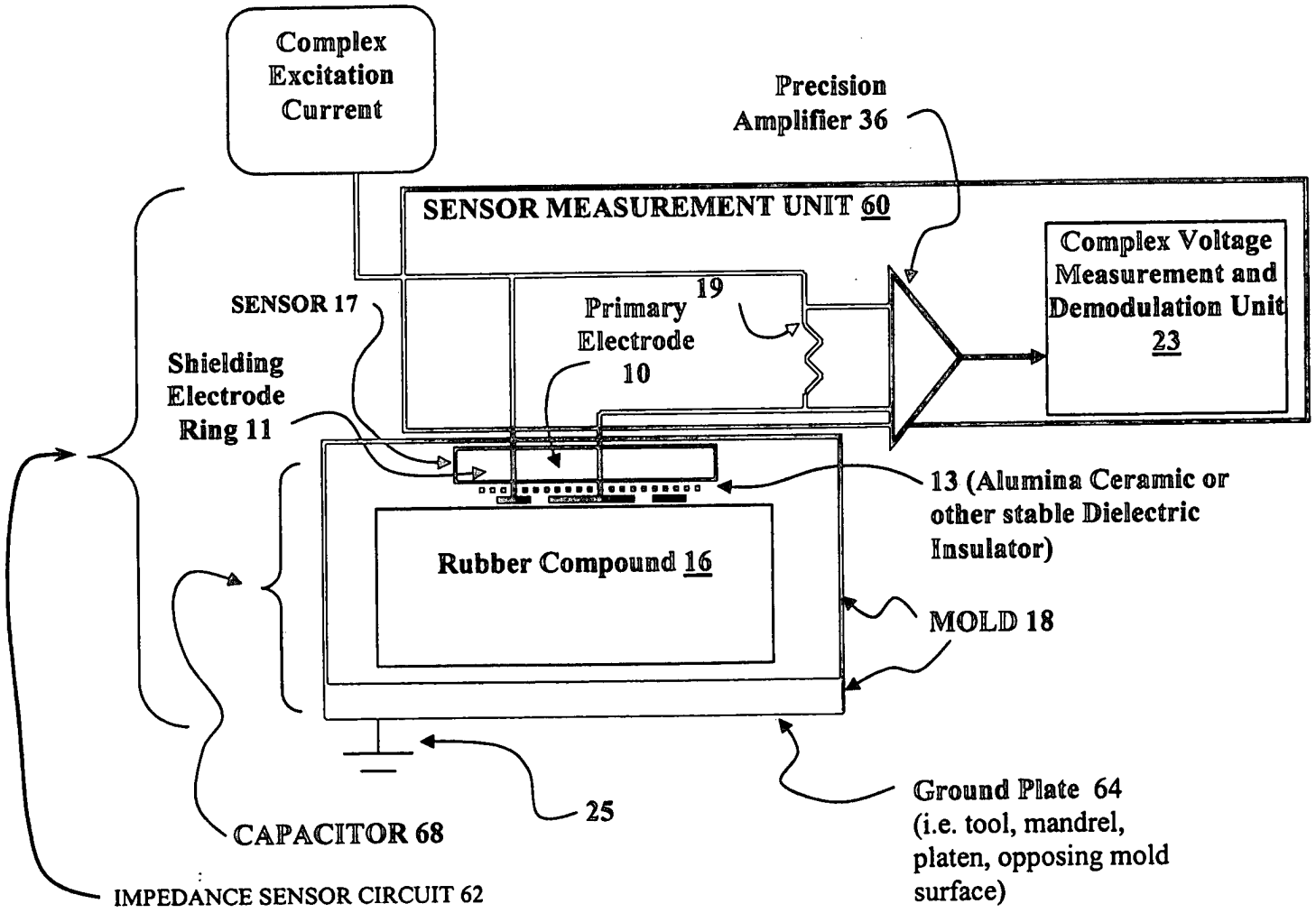

Complex Excitation Current
Precision Amplifier 36
SENSOR MEASUREMENT UNIT 60
Complex Voltage Measurement and Demodulation Unit 23
SENSOR 17
19
Primary Electrode 10
Shielding Electrode Ring 11
13 (Alumina Ceramic or other stable Dielectric Insulator)
Rubber Compound 16
MOLD 18
25
CAPACITOR 68
Ground Plate 64 (i.e. tool, mandrel, platen, opposing mold surface)
IMPEDANCE SENSOR CIRCUIT 62

FIG. 4

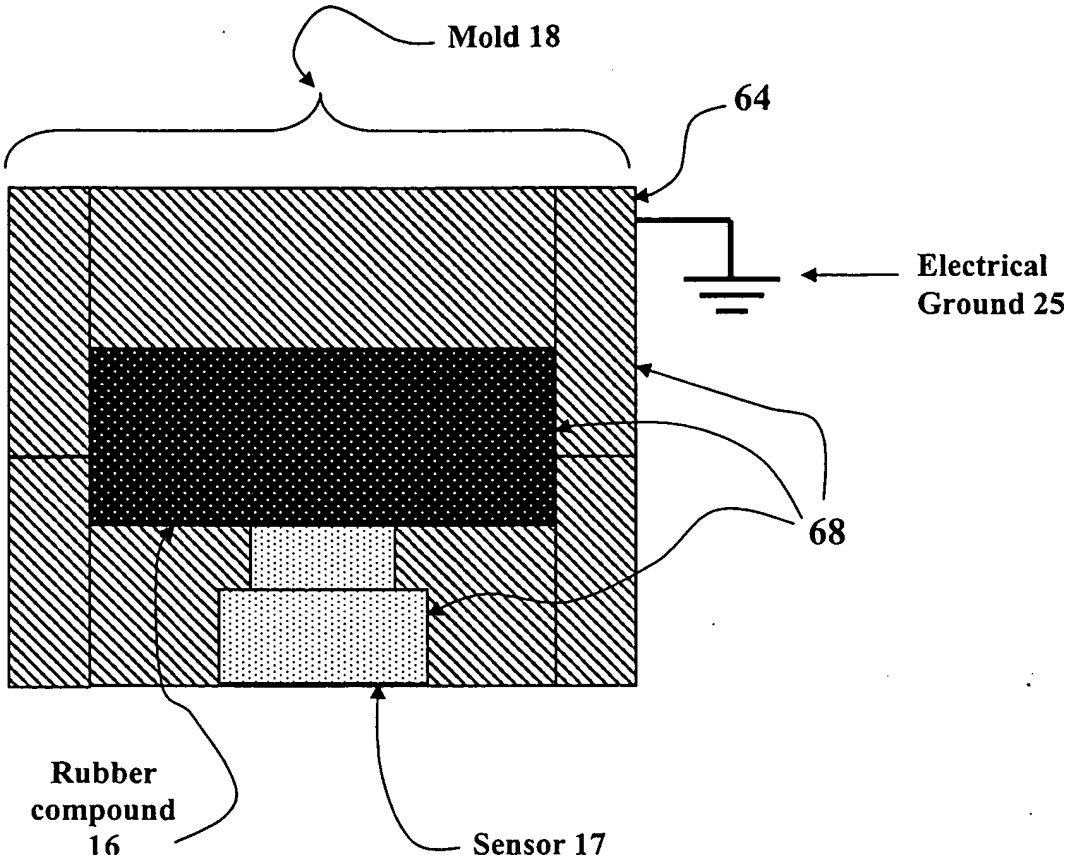

Mold 18
64
Electrical
Ground 25
68
Rubber
compound
16
Sensor 17

FIG. 5

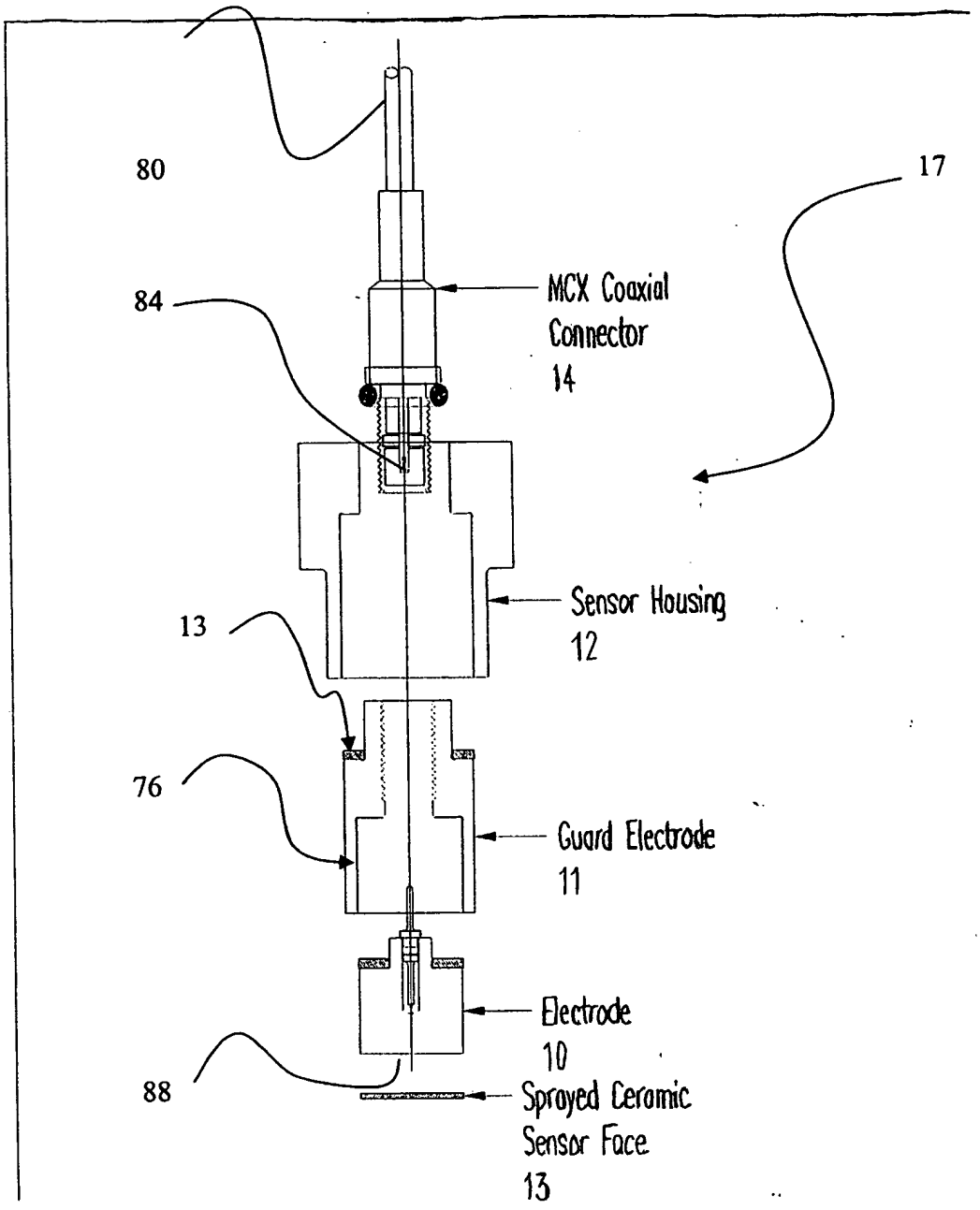

80
17
84
MCX Coaxial
Connector
14
Sensor Housing
12
13
76
Guard Electrode
11
Electrode
10
88
Sprayed Ceramic
Sensor Face
13

FIG. 6

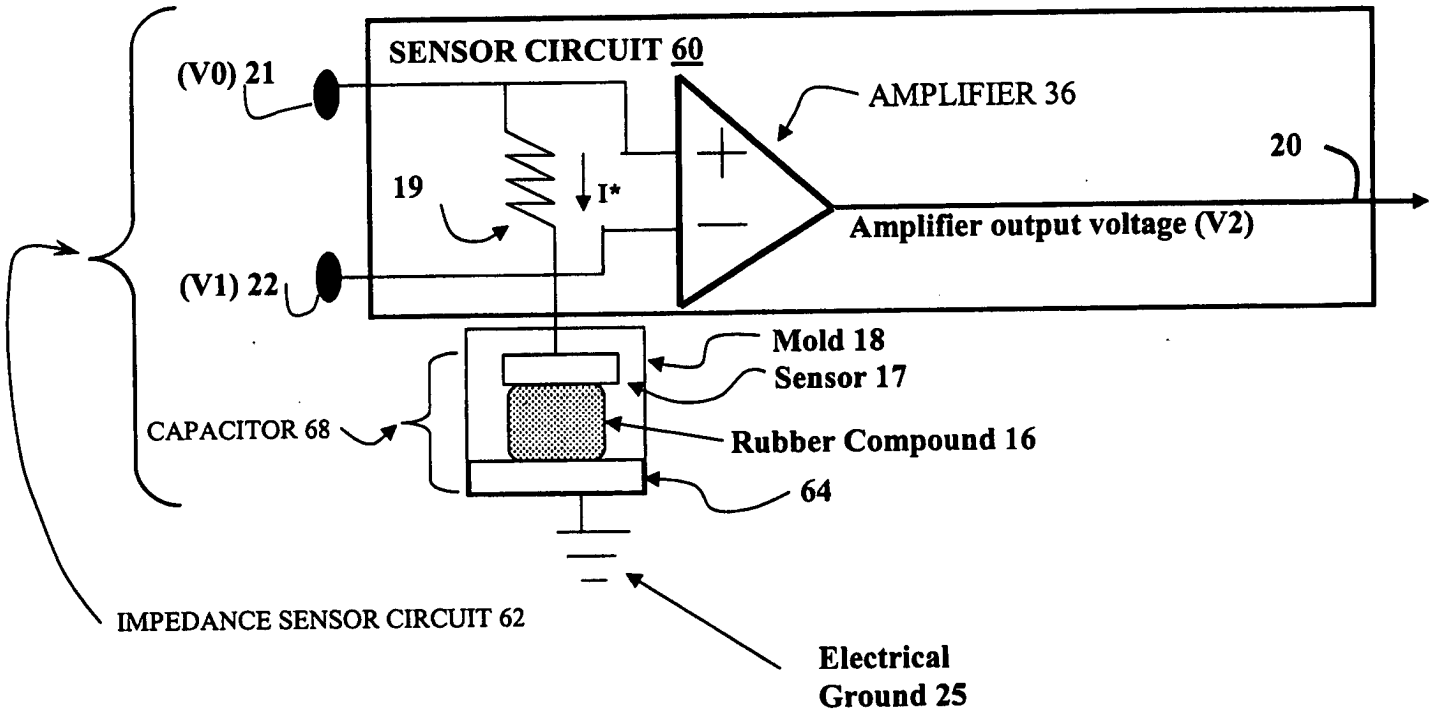

SENSOR CIRCUIT 60
(V0) 21
AMPLIFIER 36
20
19
I*
Amplifier output voltage (V2)
(V1) 22
Mold 18
Sensor 17
CAPACITOR 68
Rubber Compound 16
64
IMPEDANCE SENSOR CIRCUIT 62
Electrical
Ground 25

FIG. 7

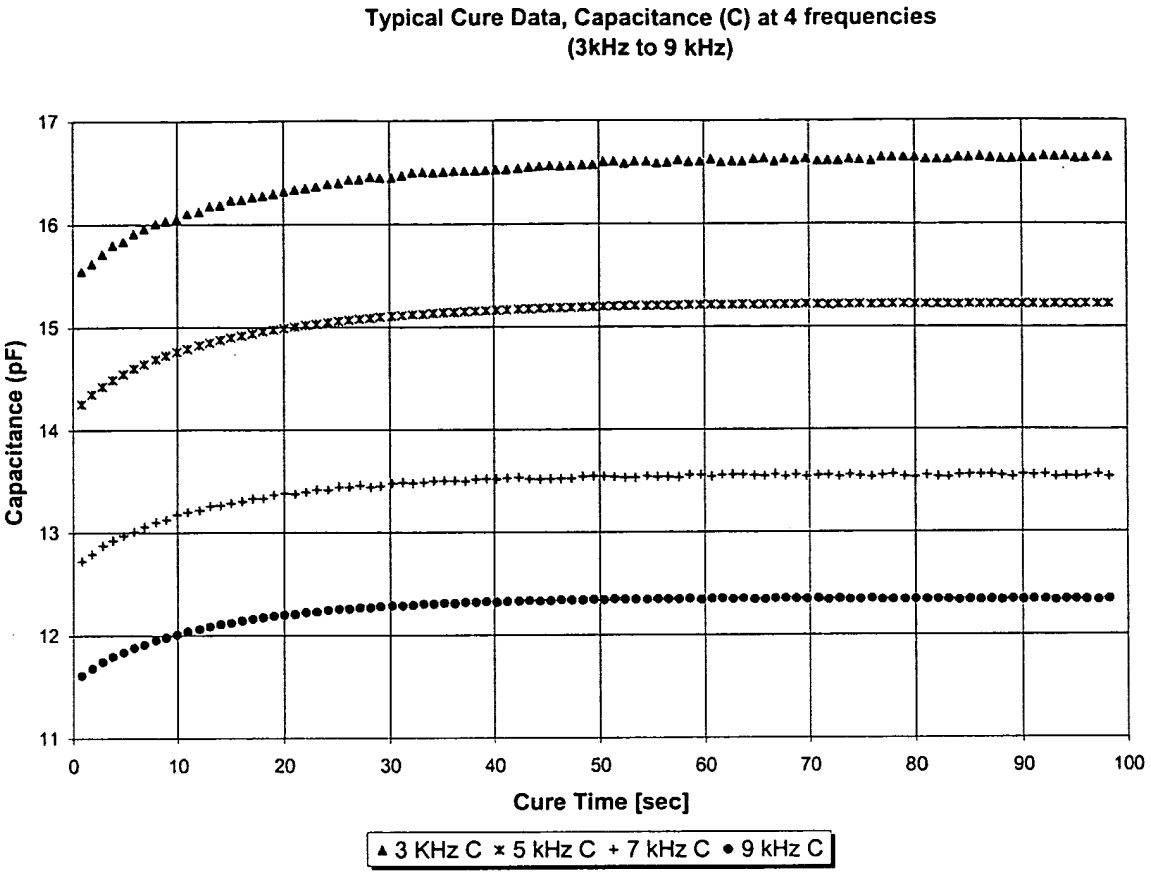

Typical Cure Data, Capacitance (C) at 4 frequencies
(3kHz to 9 kHz)
Capacitance (pF)
17
16
15
14
13
12
11
0
10
20
30
40
50
60
70
80
90
100
Cure Time [sec]
▲ 3 KHz C × 5 kHz C + 7 kHz C • 9 kHz C

FIG. 8

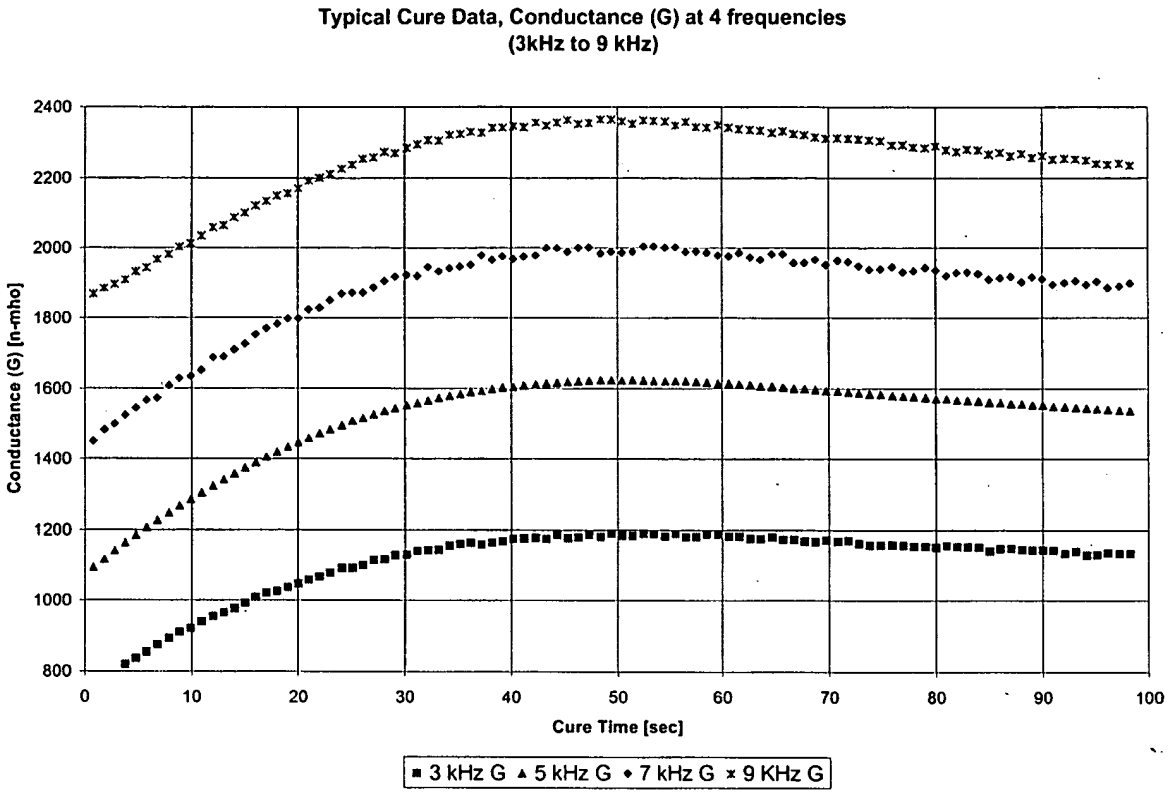
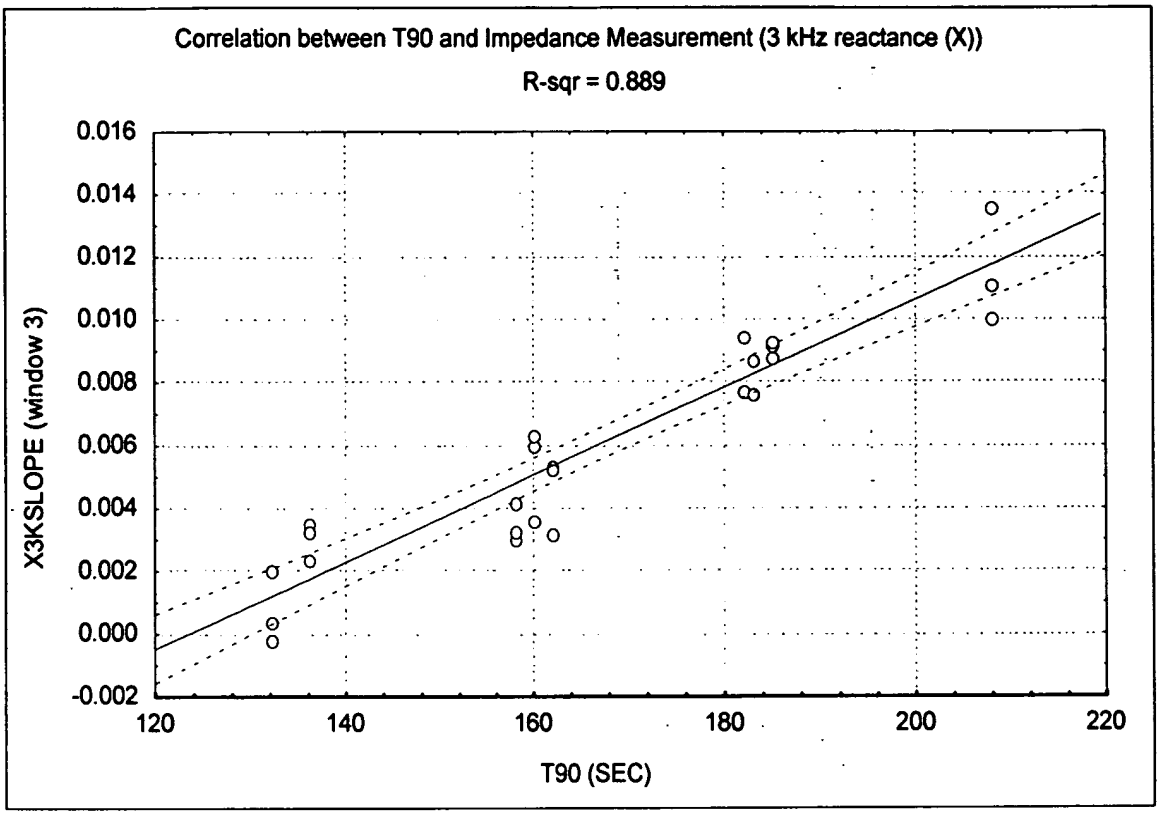

Typical Cure Data, Conductance (G) at 4 frequencies
(3kHz to 9 kHz)
Conductance (G) [n-mho]
2400
2200
2000
1800
1600
1400
1200
1000
800
0
10
20
30
40
50
60
70
80
90
100
Cure Time [sec]
3 kHz G
5 kHz G
7 kHz G
9 KHz G

FIG. 9



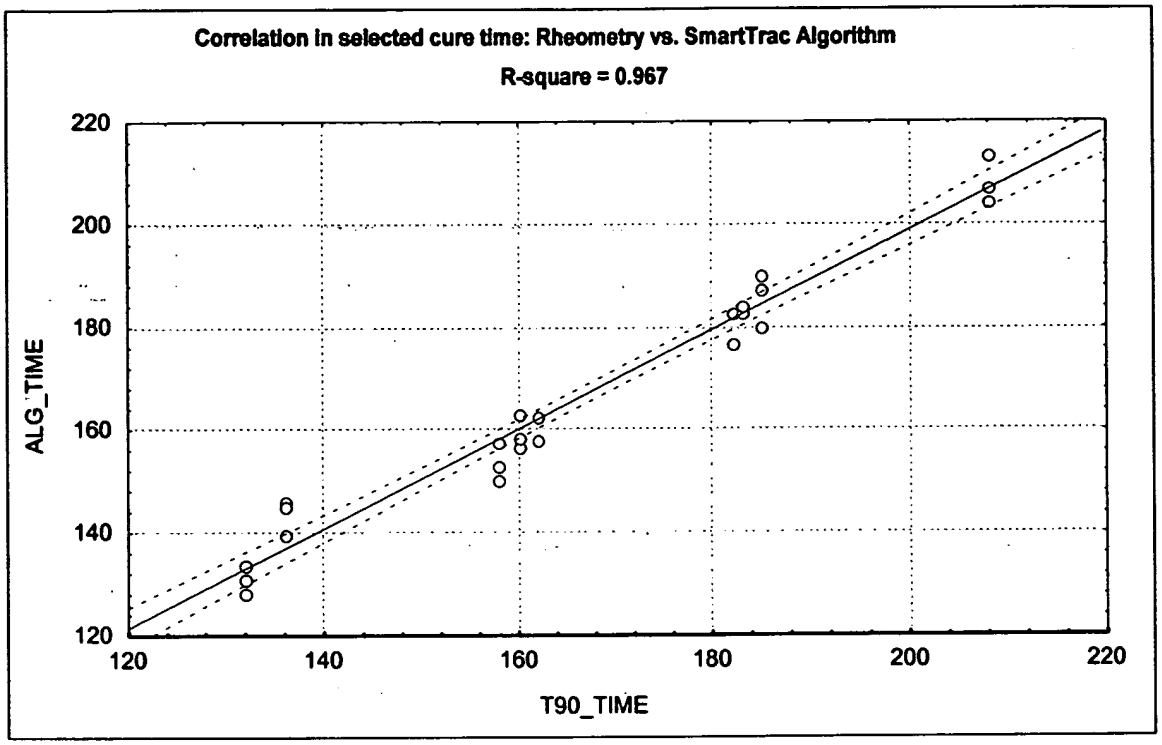
LEGEND:

o Data Point: coordinates being (for a given curing condition): Evaluator 6 determined time, and a corresponding rheometrically determined cure time.

—— Best Fit through the Data Points

- - - - 95% Confidence Intervals

FIG. 10



LEGEND:

o Data Point: coordinates being (for a given curing condition): a determined time from a selected four-term multiple regression instance of Equation 2, and a corresponding rheometrically determined cure time.

—— Best Fit through the Data Points

- - - - 95% Confidence Intervals

FIG. 11

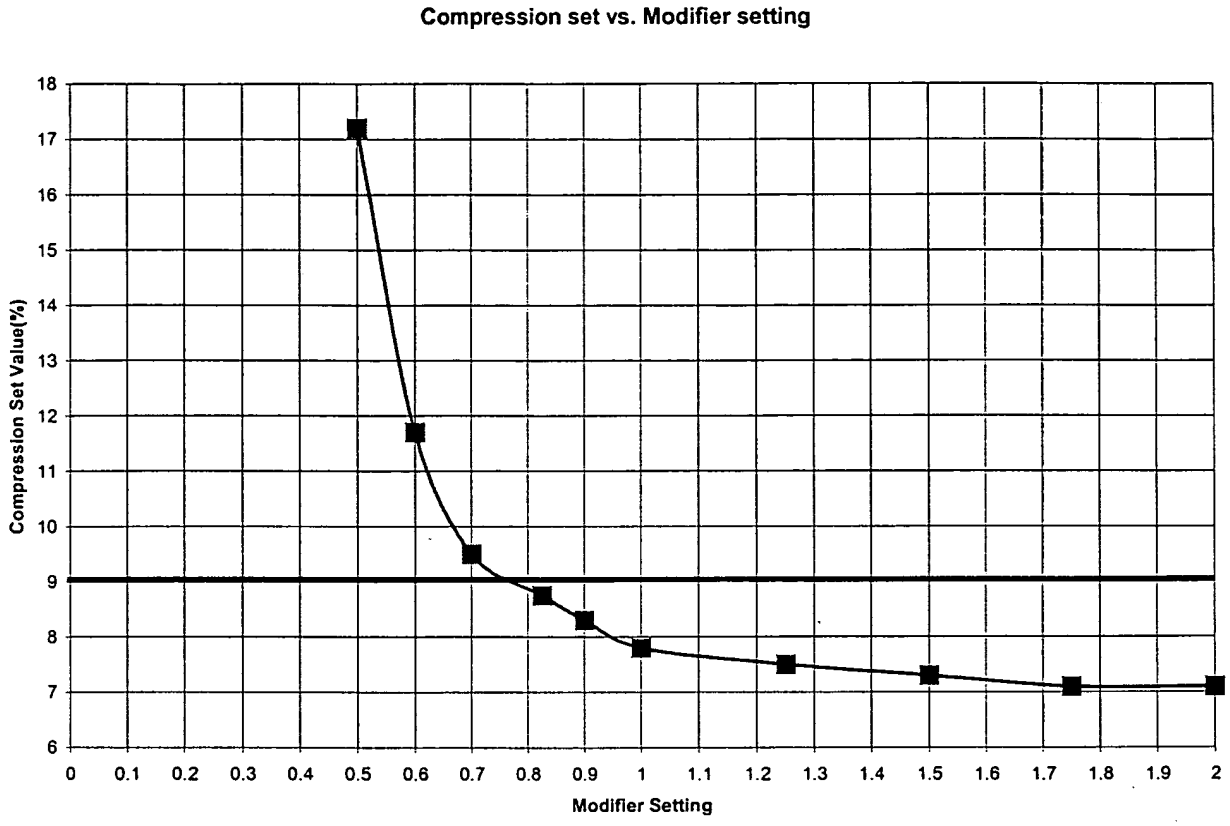

Compression set vs. Modifier setting
Compression Set Value(%)
18
17
16
15
14
13
12
11
10
9
8
7
6
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
Modifier Setting

FIG. 12

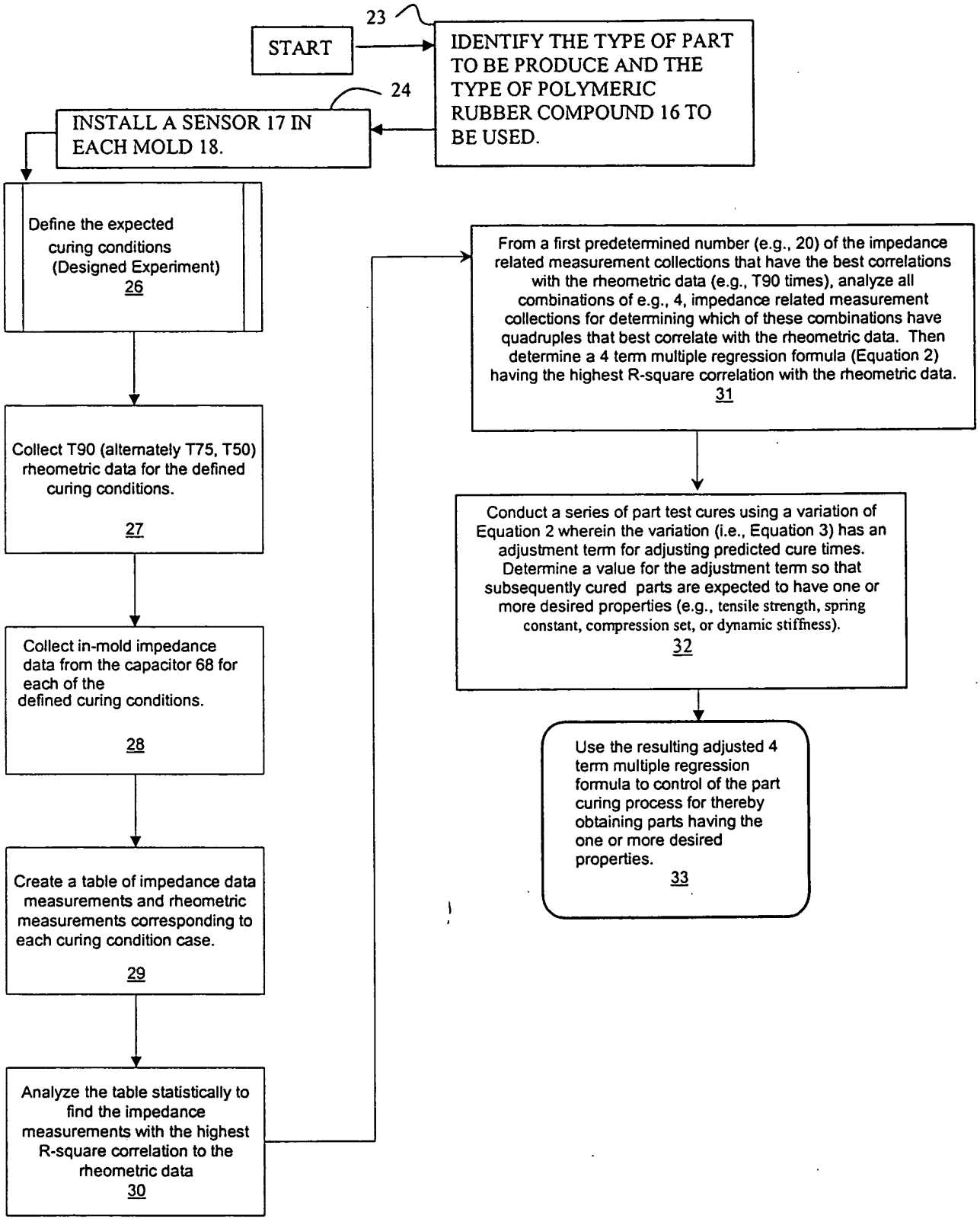

START
23
IDENTIFY THE TYPE OF PART TO BE PRODUCE AND THE TYPE OF POLYMERIC RUBBER COMPOUND 16 TO BE USED.
24
INSTALL A SENSOR 17 IN EACH MOLD 18.
Define the expected curing conditions (Designed Experiment) 26
Collect T90 (alternately T75, T50) rheometric data for the defined curing conditions. 27
Collect in-mold impedance data from the capacitor 68 for each of the defined curing conditions. 28
Create a table of impedance data measurements and rheometric measurements corresponding to each curing condition case. 29
Analyze the table statistically to find the impedance measurements with the highest R-square correlation to the rheometric data 30
From a first predetermined number (e.g., 20) of the impedance related measurement collections that have the best correlations with the rheometric data (e.g., T90 times), analyze all combinations of e.g., 4, impedance related measurement collections for determining which of these combinations have quadruples that best correlate with the rheometric data. Then determine a 4 term multiple regression formula (Equation 2) having the highest R-square correlation with the rheometric data. 31
Conduct a series of part test cures using a variation of Equation 2 wherein the variation (i.e., Equation 3) has an adjustment term for adjusting predicted cure times. Determine a value for the adjustment term so that subsequently cured parts are expected to have one or more desired properties (e.g., tensile strength, spring constant, compression set, or dynamic stiffness). 32
Use the resulting adjusted 4 term multiple regression formula to control of the part curing process for thereby obtaining parts having the one or more desired properties. 33

FIG. 13

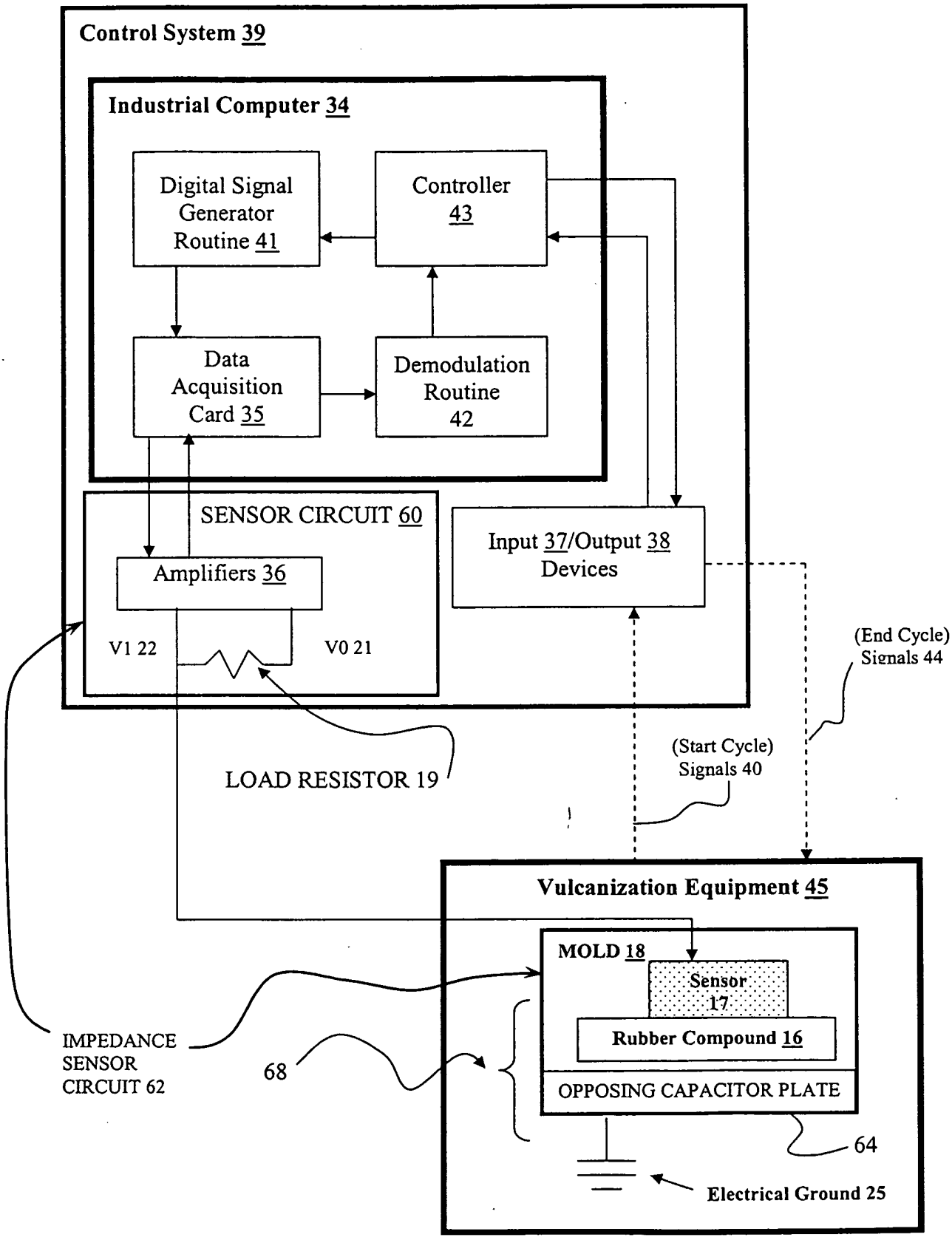
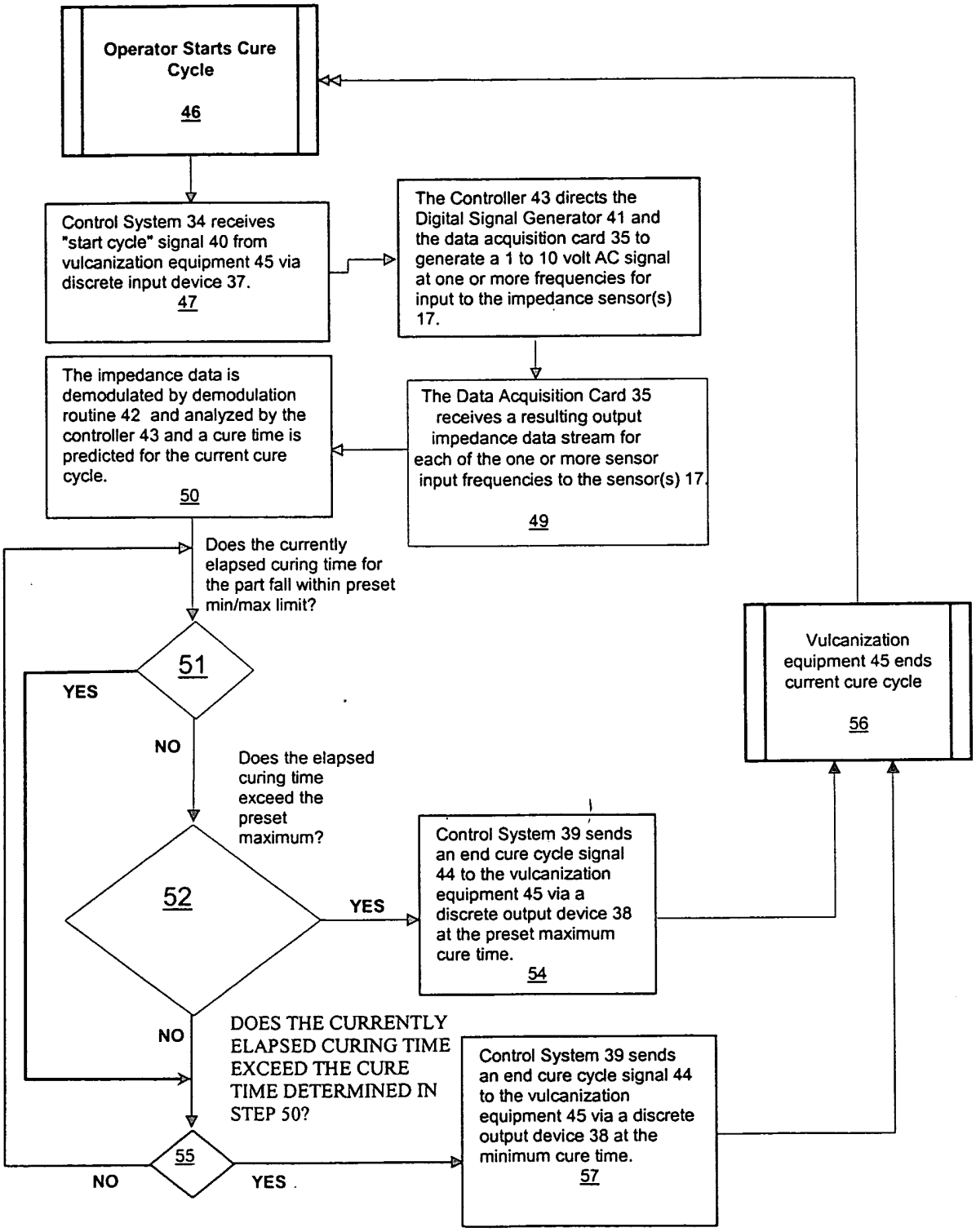

Control System 39
Industrial Computer 34
Digital Signal Generator Routine 41
Controller 43
Data Acquisition Card 35
Demodulation Routine 42
SENSOR CIRCUIT 60
Amplifiers 36
V1 22
V0 21
Input 37/Output 38 Devices
(End Cycle) Signals 44
LOAD RESISTOR 19
(Start Cycle) Signals 40
Vulcanization Equipment 45
MOLD 18
Sensor 17
Rubber Compound 16
OPPOSING CAPACITOR PLATE
64
Electrical Ground 25
IMPEDANCE SENSOR CIRCUIT 62
68

FIG. 14


Operator Starts Cure Cycle
46
Control System 34 receives "start cycle" signal 40 from vulcanization equipment 45 via discrete input device 37.
47
The Controller 43 directs the Digital Signal Generator 41 and the data acquisition card 35 to generate a 1 to 10 volt AC signal at one or more frequencies for input to the impedance sensor(s) 17.
The Data Acquisition Card 35 receives a resulting output impedance data stream for each of the one or more sensor input frequencies to the sensor(s) 17.
49
The impedance data is demodulated by demodulation routine 42 and analyzed by the controller 43 and a cure time is predicted for the current cure cycle.
50
Does the currently elapsed curing time for the part fall within preset min/max limit?
51
YES
NO
Does the elapsed curing time exceed the preset maximum?
52
YES
Control System 39 sends an end cure cycle signal 44 to the vulcanization equipment 45 via a discrete output device 38 at the preset maximum cure time.
54
NO
DOES THE CURRENTLY ELAPSED CURING TIME EXCEED THE CURE TIME DETERMINED IN STEP 50?
55
NO
YES
Control System 39 sends an end cure cycle signal 44 to the vulcanization equipment 45 via a discrete output device 38 at the minimum cure time.
57
Vulcanization equipment 45 ends current cure cycle
56

`Fig. 15

Typical Impedance data obtained during cure, Natural Rubber

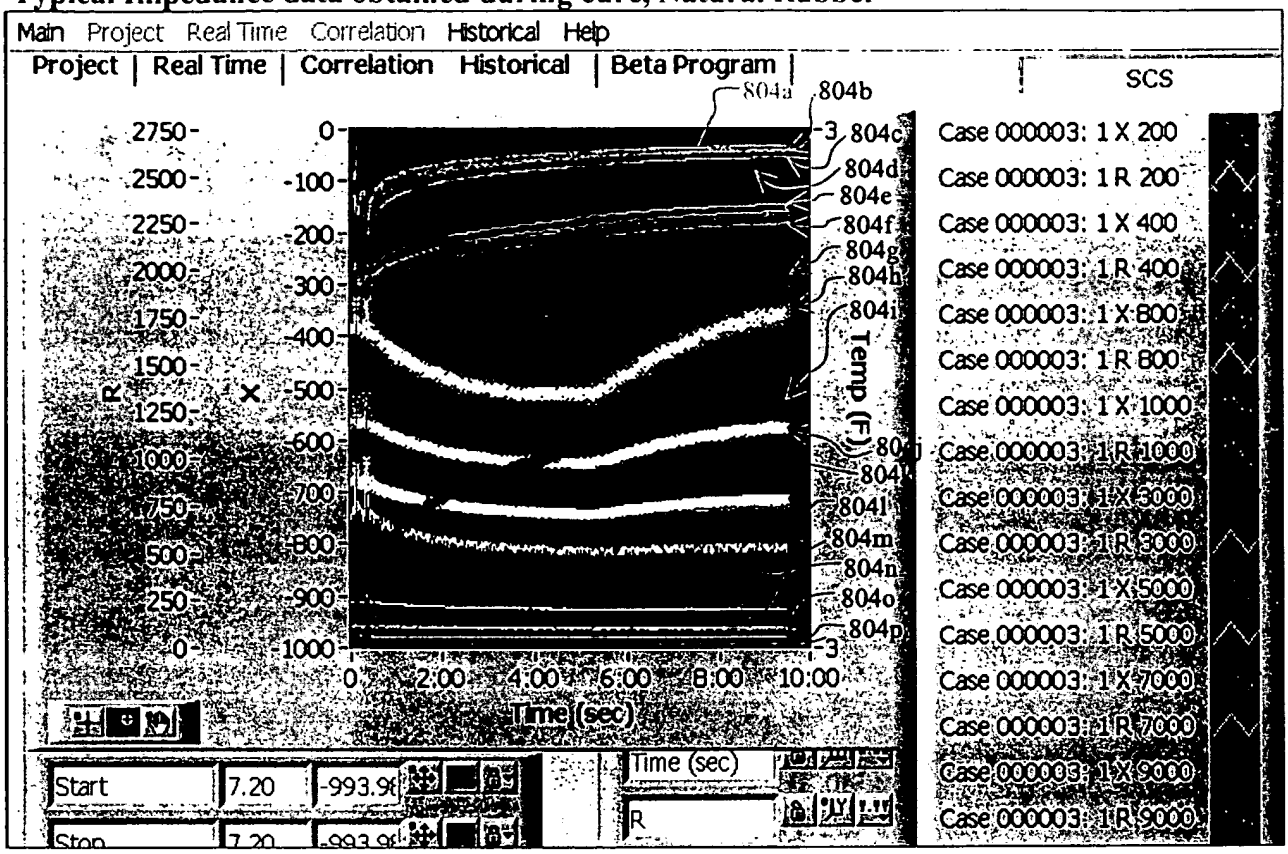


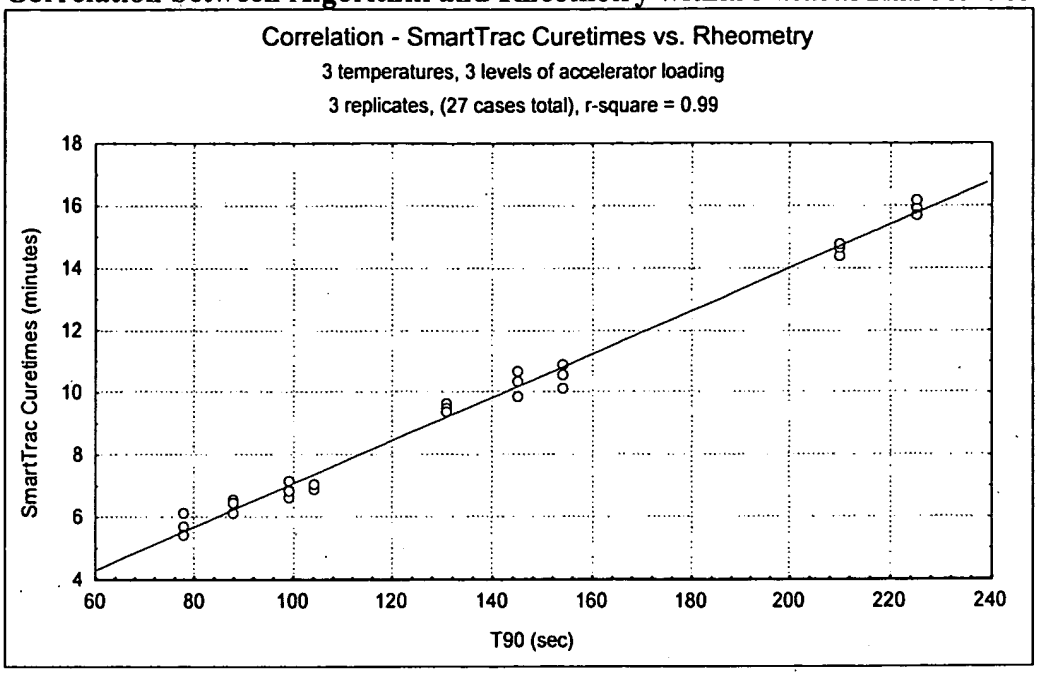
Fig. 16

Conditions and Rheometry for Natural Rubber Designed Experiment

temperature (deg C)	accelerator loading	T90 (sec)
165	low	225
175	low	99
165	nominal	210
175	nominal	131
185	nominal	88
165	high	154
175	high	104
185	high	78

Fig. 17

Correlation between Algorithm and Rheometry within Natural Rubber Designed Experiment



LEGEND:

- o Data Point: coordinates being for (a given curing condition): a determined time from a selected four-term multiple regression instance of Equation 3, and a corresponding rheometrically determined cure time.

—— Best Fit through the Data Points

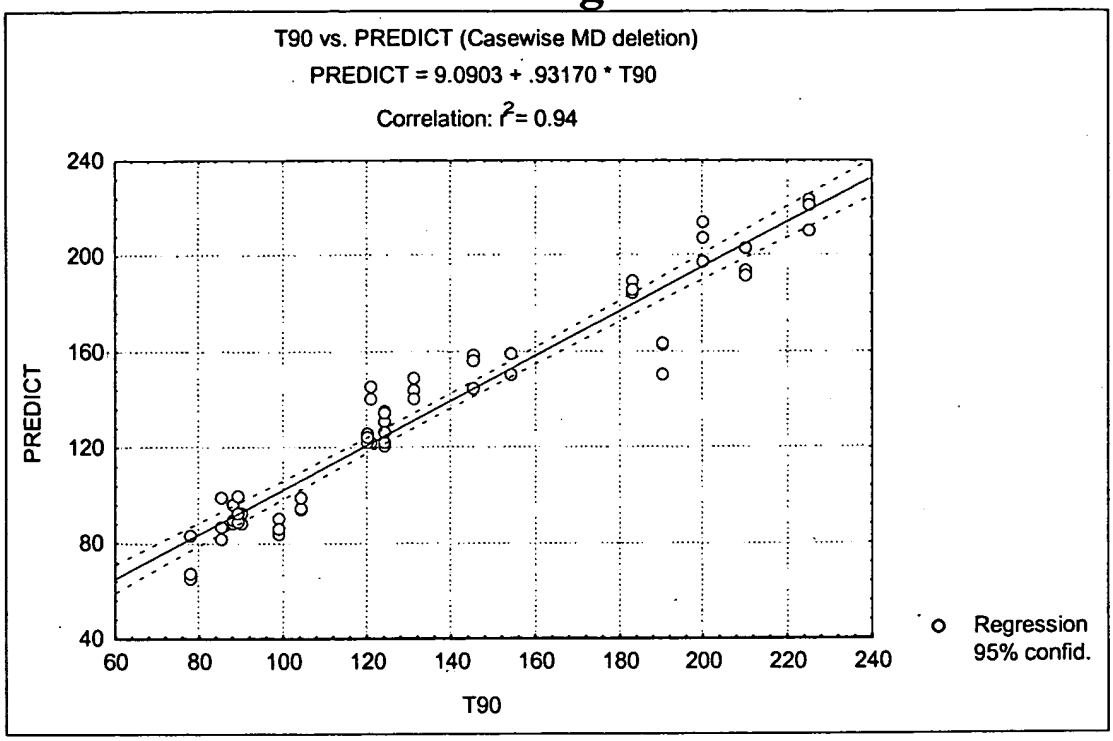
----- 95% Confidence Intervals

Fig. 18

Conditions and Rheometry for Broad Sampling of Natural Rubber Batches

Batch ID	Cure Characteristic	Hardness	Temp (C)	T90 (sec)
AA22120-1	slow curing	nominal	165	225
AA22120-1	slow curing	nominal	175	144.6
AA22120-1	slow curing	nominal	185	99
AA12120-5	nominal-production	nominal-production		
AA12120-5	nominal-production	nominal-production		
AA12120-5	nominal-production	nominal-production		
AA32120-1	fast curing	nominal	165	153.6
AA32120-1	fast curing	nominal	175	103.8
AA32120-1	fast curing	nominal	185	78
AA12259-1	nominal	soft	165	189.6
AA12259-1	nominal	soft	175	123.6
AA12259-1	nominal	soft	185	88.2
AA12189-1	nominal	hard	165	189.6
AA12189-1	nominal	hard	175	123.6
AA12189-1	nominal	hard	185	88.2
AA12120-15	nominal-production	nominal-production	165	189.6
AA12120-15	nominal-production	nominal-production	175	123.6
AA12120-15	nominal-production	nominal-production	185	88.2
AA12120-23	nominal-production	nominal-production	175	120

Fig. 19



LEGEND:

- o Data Point: coordinates being (for a given curing condition): a determined time from a selected four-term multiple regression instance of Equation 3 for natural rubber, and a corresponding rheometrically determined cure time.
- —— Best Fit through the Data Points
- ----- 95% Confidence Intervals

Fig. 20

BATCH IDENTIFIER	TEMPERATURE		
	165 C	175 C	180 C
AA22120-1 slow curing	6 samples 11:10 (predicted cure time)	6 samples 8:10 (predicted cure time)	
AA12120-57 production batch	4 samples 10:46 (predicted cure time)	7 samples 7:52 (predicted cure time)	
AA12120-58 production batch		6 samples 7:56 (predicted cure time)	8 samples 7:05 (predicted cure time)
AA32120-1 fast curing	7 samples 9:11 (predicted cure time)	5 samples 7:13 (predicted cure time)	8 samples 6:09 (predicted cure time)